

Spatial Variability of VHF FM Radio Signals with Surface Refractivity Values in Niger State, Nigeria

J. O. Eichie[1*] O. D. Oyedum[1] M. O. Ajewole[2] A. T. Adediji[2] K. C. Igwe[1] A. S. Moses[1]
1.Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria.
2.Department of Physics, Federal University of Technology, Akure, Ondo State, Nigeria
E-mail: juliaeichie@futminna.edu.ng (Corresponding author);onyedidavid@futminna.edu.ng; oludareajewole61@yahoo.com;kunleadediji2002@yahoo.co.uk;igweking4all@yahoo.com mosesdotcom@gmail.com

Abstract
Radio refractivity N exerts considerable influence on radio signals at Very High Frequency (VHF) and higher frequency bands. In particular, surface refractivity correlates positively with radio field strength, and knowledge of its temporal and/or spatial variability is important in predicting performance of terrestrial radio networks, especially at VHF frequencies. In this work, measurement of electric field strength of Frequency Modulated (FM) radio signals in Niger State, Nigeria was carried out at the onset and peak of the wet season; variation of surface radio refractivity was obtained in Minna, Niger State based on concurrent measurement of surface air temperature, pressure and relative humidity. Variation of electric field strength of FM radio signals in the wet season is found to agree in general with the observed variation of surface radio refractivity, $N_{s,}$ in Niger State, Nigeria.
Keywords: Electric field strength, surface radio refractivity, propagation

1. Introduction

Free-air radio signals are generally enhanced or degraded by atmospheric conditions. Transmission and reception of FM radio signals rely almost entirely upon the space wave component of the ground wave, which consists of the direct wave and the ground-reflected wave travelling through the troposphere from the transmitting antenna to the receiving antenna [Hall and Barclay, 1991]. A transmitting antenna supplied with power, *P,* will radiate electromagnetic waves in the entire space. These waves are propagated in all directions, through the atmosphere, from a broadcast transmitting antenna to a receiving antenna. The strength of the field created by these waves weakens as the inverse of the square of the distance from the transmitting antenna [Boithias, 1987]. Hills, buildings, trees and other physical obstacles along the signal path often reduce FM reception distance. On the other hand, a variety of atmospheric conditions serve to enhance the distance over which FM radio signals can be received, thereby sometimes enabling the signals to reach unintended locations where they may constitute potential interference to some other stations.

Radio signals consist of the electric and magnetic field components. The electric field component is measured in terms of the change of potential over a given distance, which may be in volts per meter, and this is known as the electric field strength [Morris and William, 1973]. This measure is often used in measuring the strength or intensity of radio signals (electromagnetic wave) at given points to determine the signal coverage area. The electric field strength of radio signals at VHF and higher frequency bands generally vary in the troposphere due to variations in the refractivity conditions of the air, which in turn depend on variations in temperature, pressure and water vapour pressure. These variations show climatic, seasonal and diurnal trends [Hall, 1979]. It is a well established fact that wave propagation in the metric, decimetric and centimetric (i.e. V.H.F., U.H.F., and S.H.F.) bands can be profoundly influenced by the variations in the tropospheric characteristics of the radio path by virtue of the changes in its refractive index, the effect of inversion layers resulting in ducting, and meteorological fronts [Owolabi and Williams, 1970].

The troposphere is the lowest layer of the atmosphere. It extends from the sea level to an altitude that is dependent on geographical latitude and season. The height of the upper boundary varies with atmospheric conditions; at middle latitudes it may reach about 17 km in anticyclones and decline to less than 7 km in depressions [Hall, 1979]. In the troposphere, changes in temperature, pressure and humidity, as well as clouds and rain, influence the way in which radio waves propagate from one point to another. In normal situations, temperature decreases with altitude in the troposphere and as a result, warm air near the surface of the Earth readily rise, being less dense than the colder air above it. Such vertical movement or convection of air is largely responsible for the clear-air effects which gives rise to variation in atmospheric refractive index.

The variation of the refractive index in the horizontal direction is negligible compared with the vertical profile. Large-scale variation of refractive index with height, and the extent to which it changes with time, are useful parameters for assessing the propagation characteristics of the troposphere which may vary greatly, depending on the type of air mass [Gossard, 1977]. Variations in vertical refractivity gradients change the propagation conditions to non-standard conditions which have serious implications with regard to signal loss, signal enhancement and anomalous propagation [Valtr and Pechac, 2005]

Refractivity variations are more pronounced in tropical climates. Diurnal and seasonal variations have been observed on VHF paths in tropical countries like Nigeria, Ghana and Kuwait [Owolabi and Williams, 1970; Oyedum and Gambo, 1994]. The surface refractivity gradient, which also depends on N_s determines the refractivity condition of the atmosphere which may be in form of a normal, subrefractive, superrefractive or ducting layer, each of which has important influences on propagation of VHF, UHF and microwaves in the atmosphere [Kolawole, 1980]. Seasonal variations in N_s have been found to agree in general with the observations of the variation of radio field strength at VHF and UHF in Nigeria [Owolabi and Williams, 1970]. The radio refractivity in the first 10 km of the troposphere, known as surface radio refractivity, N_s. has high correlation with the electric field strength of radio waves [Bean and Cohoon, 1961; Hall, 1979]. Oyedum and Gambo (1994) obtained similar results and a correlation coefficient of 0.73 between N_s and transhorizon VHF field strength values in Northern Nigeria; Oyedum (2009) showed that based on N_s variability, substantial climate-related differences exist between the seasonal variability of VHF field strength and radio horizon distance in two Nigerian stations of Lagos (06^0 35′N, 03^0 20′E) on the Atlantic coast and Kano (12^0 03′N,06^0 42′E) in sub-Sahara Northern Nigeria.

Surface refractivity is also known to generally correlate well with the parameter dN representing the refractivity gradient in the first one kilometer of height above the Earth's surface [Hall, 1979; Adebanjo, 1977; Kolawole, 1980]. More recently Falodun and Ajewole (2006) reported considerable diurnal variations of refractive modulus at 100 m altitude in Nigeria. Lane and Bean (1963) obtained correlation coefficient of 0.70 between VHF field strength and N_s and 0.71 between VHF field strength and ΔN. Decrease of N with height causes radio waves to curve downwards, and to a degree which depends on the vertical refractivity gradient. Refractive index bending causes extension of the radio horizon beyond the optical horizon.

The refractive properties of the troposphere is expressed by the radio refractivity, N, given by

$$N = (n - 1) \times 10^6 \quad (1)$$

where n is the refractive index.

N depends on meteorological factors of air pressure, P, (hPa), air temperature, T, (K) and water vapour pressure, e, (hPa), and are related as (Smith and Weintraub, 1953).

$$N = (77.6/T) \times (P + 4810\, e/T) \quad (2)$$

where T = air temperature (K), P = air pressure (hPa) and e = water vapour partial pressure (hPa). The water vapour partial pressure is given by (Hall, 1979):

$$e = 6.11\exp\left[\frac{19.7t_D}{(t_D+273)}\right] \quad (3)$$

where t_D = dew point temperature in ^oC.

2. Methodology

Electric field strength measurements of two FM radio stations in Minna were carried out at the onset and peak of the wet season (April and September). The measurements were carried out in all the local government areas in Niger State, situated in central Nigeria, between latitude 8.3^o and 11.5^o North and longitude 3.6^o and 7.4^o East. The parameters of the two broadcasting stations used in this study are as shown in Table 1 while Figure 1 shows the locations of the station on a map of Niger State.

Table 1: Parameters of the two FM transmitting stations used in this study.

Name of Station	Crystal FM	Power FM
Frequency	91.2 MHz	100.5 MHz
Maximum Transmitter Power	35 kW	20 kW
Operating Transmitter Power	18.2 kW	9.12 kW
Antenna Height above sea level	450 m	540 m
Location	Minna	Bida
Geographical coordinates	9.64^o North and 6.59^o East	9.09^o North and 6.04^o East

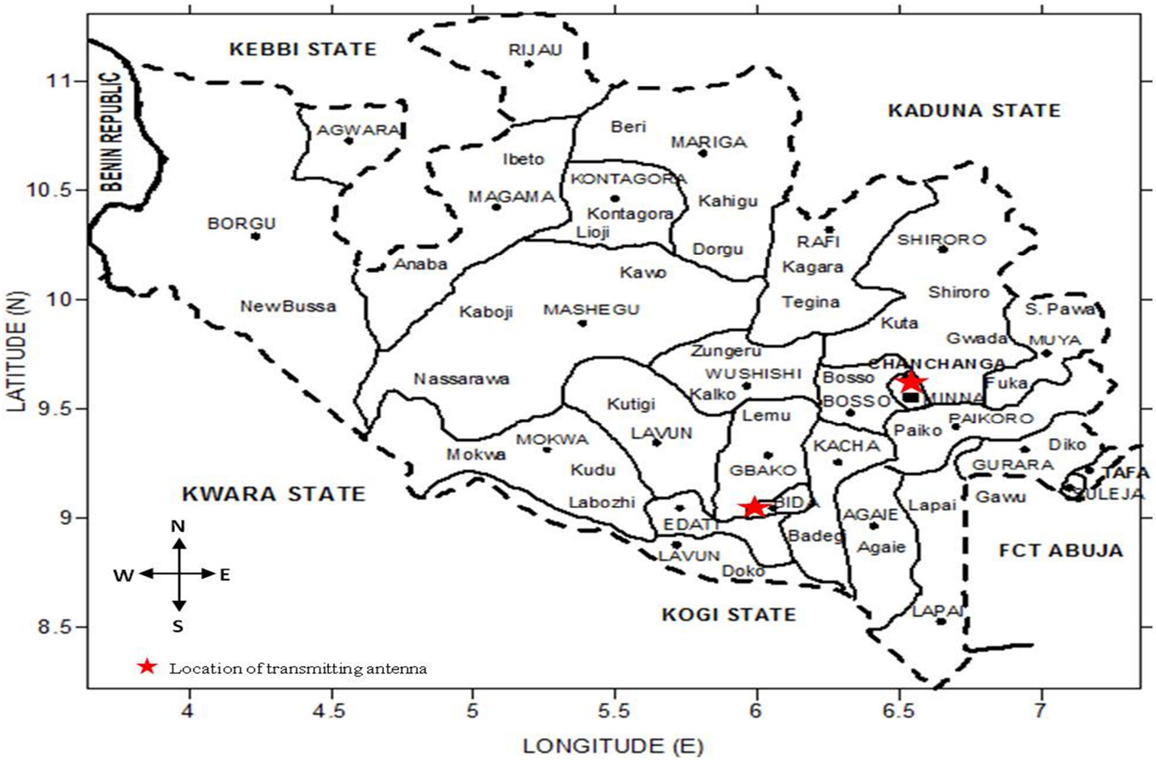

Figure 1: Map of Niger State showing the Local Government Areas, some towns, and the locations of the two FM transmitting stations.

Electric Field strength measurements of signals from Crystal FM (91.2 MHz), Minna, and Power FM (100.5 MHz), Bida were taken using a Digital Signal Level meter covering the range 30-120 dBμV. The measurements were taken at the base of the transmitting antennas, and at major towns and villages in the local government areas of Niger State, as far as accessibility by the major and minor road networks permitted, along radial routes with the transmitting antennas at focus.

Measurements were also taken at neighbouring villages in the Federal Capital Territory, Abuja. The longitude, latitude, altitude and distance from the reference point (i.e. location of the transmitting antennas) were also noted at every location using a Global Positioning System (GPS), a handheld personal navigator (GPS-72). The measurements were carried out between 8:30 am and 4:00 pm Local Time (LT) in the months of April and September.

3. Results

Contour maps of coverage areas of signals from Crystal FM (91.2 MHz) and Power FM (100.5 MHz) were drawn using the coordinates of the various locations and the signal levels measured at the onset and peak of wet season using Surfer8 application software. These contour maps were respectively overlaid on the map of Niger State to give a pictorial view of the coverage areas of the two radio stations, as well as to determine optimum coverage areas for the stations based on the following classifications:

- Primary Coverage Area (signal level value greater than or equal to 60 dBμV).
- Secondary Coverage Area (signal level value greater than 30 dBμV but less than 60 dBμV).
- Fringe Coverage Area (signal level value greater than 0 dBμV but less than 30 dBμV).

3.1 Coverage Areas of Crystal FM - 91.2 MHz, Minna.

Contours of the coverage area of Crystal FM (91.2 MHz) radio signals at the onset and peak of the wet season were overlaid on the map of Niger State as shown in figures 3 and 4.

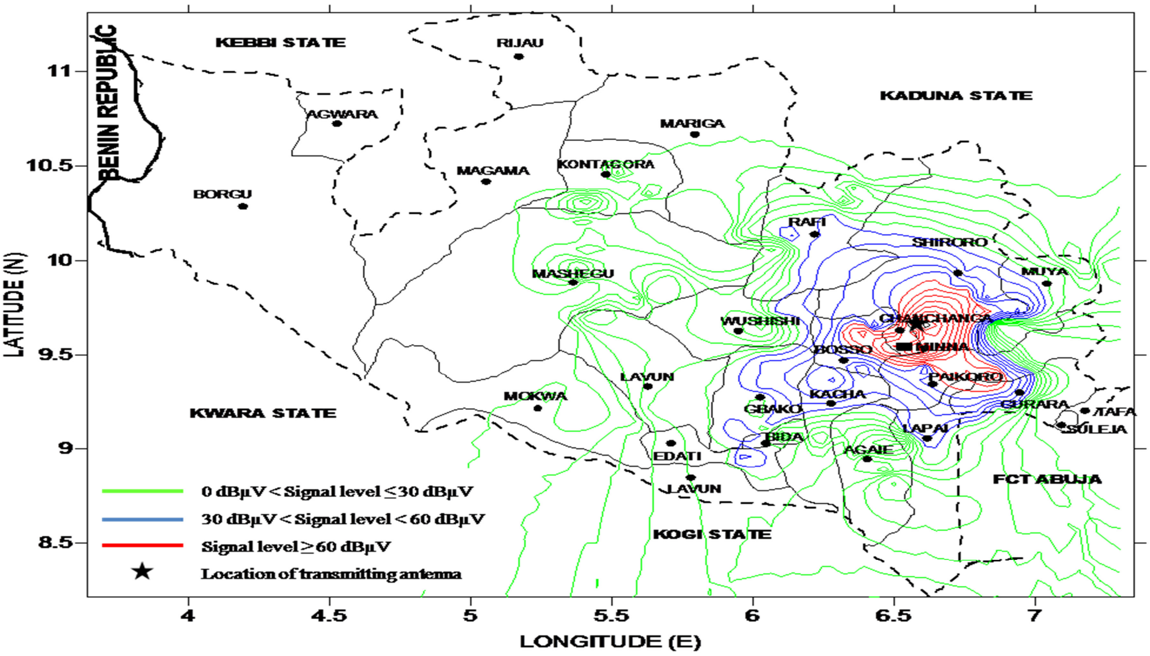

Figure 3: Contours of Coverage Area for Crystal FM (91.2 MHz) in Niger State at the onset of the wet season

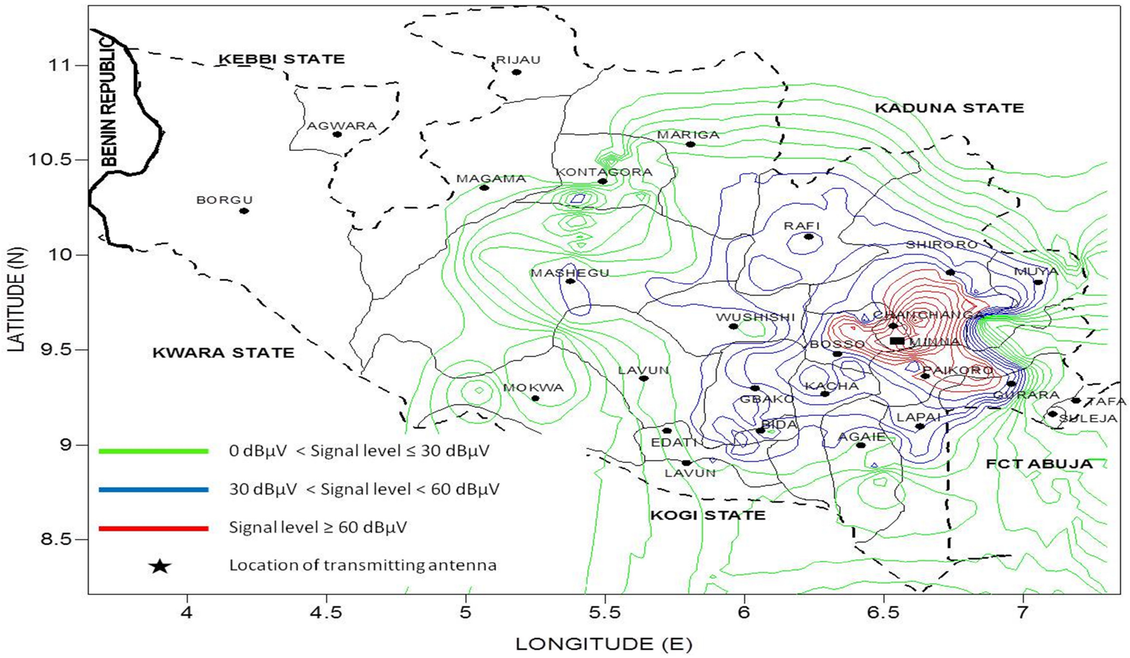

Figure 4: Contour of the Coverage Areas for 91.2 MHz FM Minna at the Peak of Wet Season

Approximate percentages of the Local Government Areas of the State in the 3 service areas at the onset and peak of wet season were compared as shown in Table 2.

Table 2: Percentage of Local Government Areas covered by Crystal FM (91.2 MHz)

Local Government Area	Onset of Wet Season				Peak of Wet Season			
	% of LGA with Grade A	% of LGA with Grade B	% of LGA with Grade C	**Total % of LGA covered**	% of LGA with Grade A	% of LGA with Grade B	% of LGA with Grade C	**Total % of LGA covered**
Agaie	0	3	97	**100**	0	20	80	**100**
Agwara	0	0	0	**0**	0	0	0	**0**
Bida	0	15	85	**100**	0	4	96	**100**
Borgu	0	0	0	**0**	0	0	0	**0**
Bosso	60	40	0	**100**	60	40	0	**100**
Chanchanga	100	0	0	**100**	100	0	0	**100**
Edati	0	10	90	**100**	0	20	80	**100**
Gbako	0	50	50	**100**	0	100	0	**100**
Gurara	5	35	35	**75**	10	40	40	**90**
Katcha	0	45	55	**100**	0	70	30	**100**
Kontagora	0	0	60	**60**	0	3	70	**73**
Lapai	4	16	80	**100**	6	24	70	**100**
Lavun	0	0	100	**100**	0	5	95	**100**
Magama	0	0	5	**5**	0	0	25	**25**
Mariga	0	0	40	**40**	0	10	65	**75**
Mashegu	0	0	50	**50**	0	10	75	**85**
Mokwa	0	0	40	**40**	0	0	80	**80**
Muya	0	25	68	**93**	0	30	67	**97**
Paikoro	30	35	20	**85**	35	30	26	**91**
Rafi	0	25	65	**90**	0	80	20	**100**
Rijau	0	0	0	**0**	0	0	0	**0**
Shiroro	20	40	30	**90**	24	45	25	**94**
Suleja	0	0	0	**0**	0	0	5	**5**
Tafa	0	0	0	**0**	0	0	0	**0**
Wushishi	0	20	80	**100**	0	10	90	**100**
Total	24	52	72	80	24	68	72	84

3.2 Coverage Areas of Power FM – 100.5 MHz, Bida.

Contours of the coverage area of Power FM (100.5 MHz) radio signals at the onset and peak of the wet season were overlaid on the map of Niger State as shown in Figures 5 and 6.

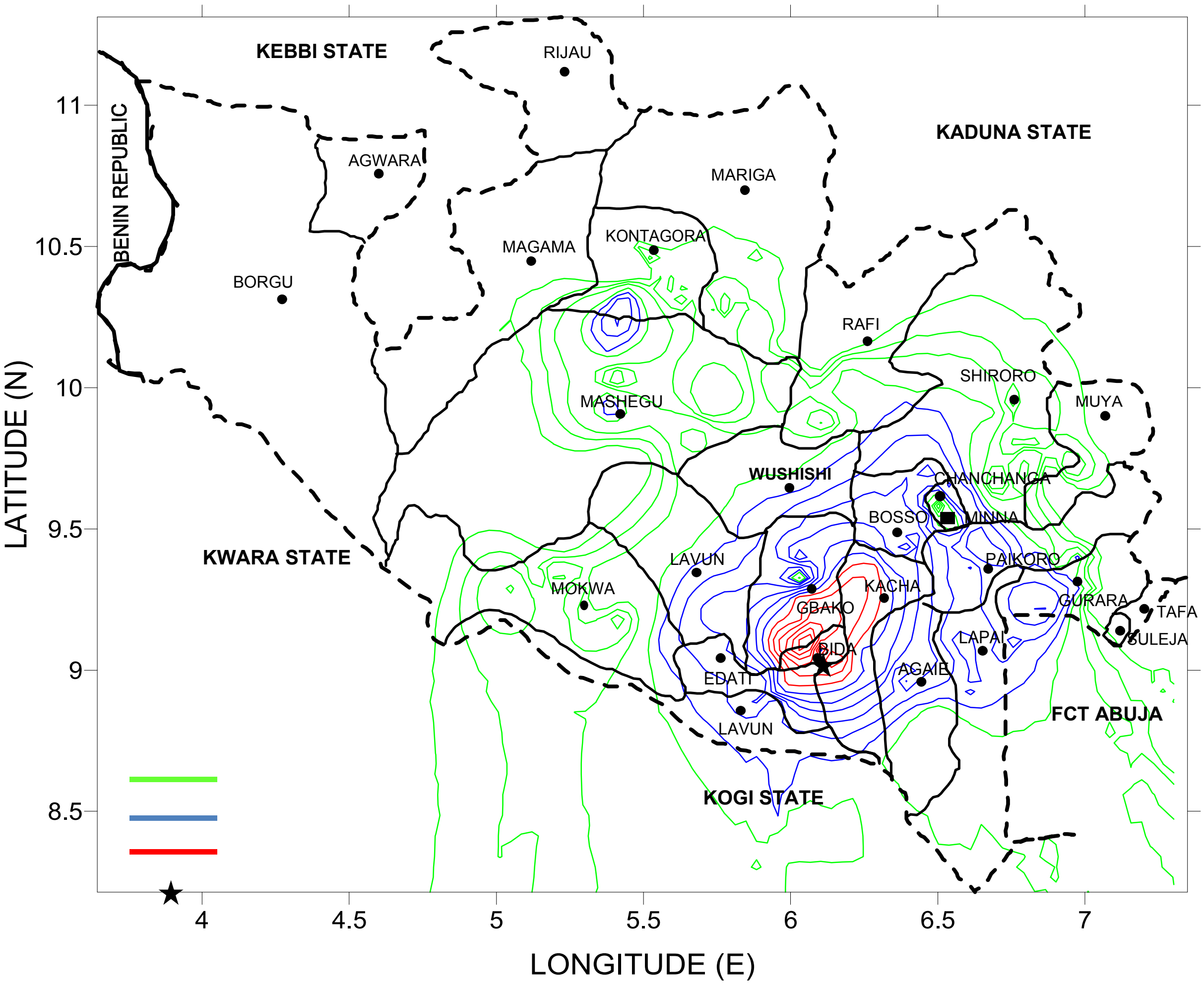

Figure 5: Contour of Coverage Areas for Power FM (100.5 MHz) in Niger State at the Onset of the Wet Season

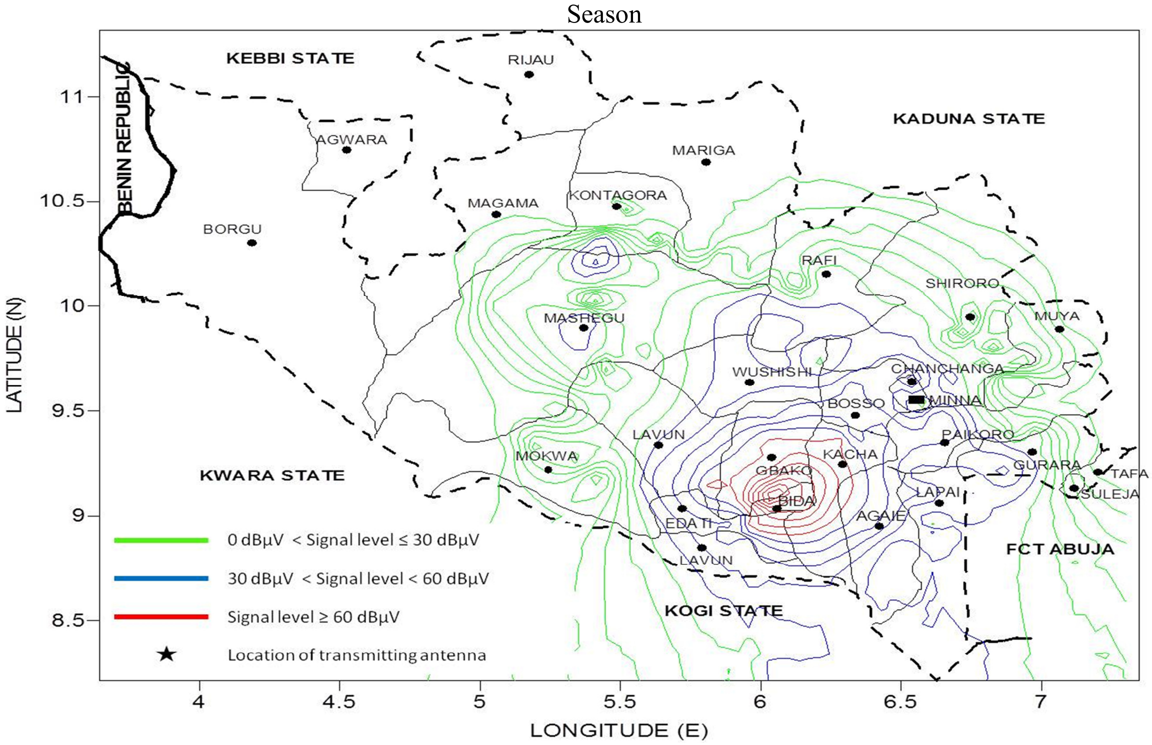

Figure 6: Contour of the Coverage Areas for 100.5 MHz Power FM Bida at the Peak of Wet Season.

Approximate percentages of the Local Government Areas of the state in the 3 service areas at the onset and at the peak of wet season were compared as shown in Table 3.

Table 3: Percentage of Local Government Areas covered by Power FM (100.5 MHz)

Local Government Area	Onset of Wet Season				Peak of Wet Season			
	% of LGA with Grade A	% of LGA with Grade B	% of LGA with Grade C	Total % of LGA covered	% of LGA with Grade A	% of LGA with Grade B	% of LGA with Grade C	Total % of LGA covered
Agaie	0	50	50	**100**	0	100	0	**100**
Agwara	0	0	0	**0**	0	0	0	**0**
Bida	100	0	0	**100**	100	0	0	**100**
Borgu	0	0	0	**0**	0	0	0	**0**
Bosso	0	100	0	**100**	0	100	0	**100**
Chanchanga	0	20	80	**100**	0	95	5	**100**
Edati	10	90	0	**100**	15	85	0	**100**
Gbako	40	54	4	**98**	55	45	0	**100**
Gurara	0	45	30	**75**	0	45	55	**100**
Katcha	40	60	0	**100**	50	50	0	**100**
Kontagora	0	5	50	**55**	0	10	30	**40**
Lapai	0	10	90	**100**	0	100	0	**100**
Lavun	0	50	50	**100**	0	55	45	**100**
Magama	0	0	10	**10**	0	0	25	**25**
Mariga	0	0	25	**25**	0	0	25	**25**
Mashegu	0	4	50	**54**	0	10	70	**80**
Mokwa	0	0	80	**80**	0	0	70	**70**
Muya	0	0	70	**70**	0	0	80	**80**
Paikoro	0	40	30	**70**	0	45	50	**95**
Rafi	0	0	50	**50**	0	30	70	**100**
Rijau	0	0	0	**0**	0	0	0	**0**
Shiroro	0	5	80	**85**	0	20	75	**95**
Suleja	0	0	5	**5**	0	0	50	**50**
Tafa	0	0	0	**0**	0	0	50	**50**
Wushishi	0	10	90	**100**	0	20	80	**100**
Total	16	56	68	84	16	60	60	88

4. Discussion of Results

The peak of the wet season recorded higher signal strength values as compared to the onset of wet season for both Crystal FM (91.2 MHz) and power FM (100.5 MHz). This, resulted in increase in the coverage areas as revealed in Tables 1 and 2. Oyedum *et a.l* (2009) investigated monthly averages of reduced-to-sea level refractivity, N_o, using a two-year data (January 2008 to December 2009) in Minna to explore the seasonal trend and seasonal variability of radio refractivity. The result obtained showed higher N_o values in the wet season and lower values in the dry season. The month of September (peak of wet season) had mean monthly refractivity value of 385 N-units and the month of April (Onset of wet season) had a lower mean monthly value of 359 N-units.

It is also observed that towns and villages such as New Bussa, Rijau, Sabon Gari, Kali, and Karunji in Borgu, Agwara and Rijau Local Government Areas respectively are not served by either of the FM radio stations in Niger State. There is no town or village that simultaneously enjoys Grade A service quality from both FM radio stations. However, few towns and villages simultaneously enjoy Grade A quality of service from either of the FM stations and Grade B quality of service from the other. Some of these towns are: Minna, Bosso, Paiko, Bida, Lemu, Chanchanga, Gidan Kwanu, Patinda, and Alashe. Less than 50% of Niger State enjoys service of at least Grade B quality from either of the FM stations.

5. Conclusion

Variation in the strength of Niger State FM radio signals is also in general agreement with the observation of radio field strength at VHF and UHF reported for Nigeria by Owolabi and Williams (1970), which was characterized by high field strength during the wet season and deep fades during the dry season.

From the study, Niger State FM radio stations may frequently not constitute source of interference to neighbouring States such as Kaduna and Kwara States, since they receive weak or no signals from the radio stations in the State. However, few neighbouring villages in Kogi State receive Grade B quality of service from Power FM (100.5 MHz). Also, some neighbouring villages in the Federal Capital Territory, Abuja, such as Gawu and Tunganusman, receive Grade B quality of service from Crystal FM (91.2 MHz) and Power FM (100.5 MHz). Hence such neighbouring areas receiving Grade B service from these stations may be exposed to some level of interference on their own stations.

Reference

Adebanjo, T. I. (1977): A semi-empirical radio refractive index variation over Nigeria. Bull. Nig. Inst. Phys. Vol.2, No.2, pp.69-78.

Bean, B. R. and Cahoon, B. A. (1961): Correlation of Monthly Median Transmission Loss and Refractive Index Profile Characteristics. J. Res. N.B.S. 65 D, No.1, pp. 67-74.

Boithias, L. (1987): Radio Wave Propagation, Translated by David Beeson, McGraw-Hill, New York, pp. 20-43.

Falodun, S. E. and Ajewole, M. O. (2006): Radio refractive index in the lowest 100m layer of the troposphere in Akure, South Western Nigeria, *Journal of Atmospheric and Solar-Terrestrial Physics,* Vol. 68, 236–243.

Gossard, E. E. (1977): Refractive Index Variance and its Height Distribution in Different Air Masses, Radio Science, Vol. 12, pp. 89-105.

Hall, M. P. M. (1979): Effects of the Troposphere on Radio Communication. Peter Peregrinus Ltd, London, United Kingdom, pp. 100-202.

Hall, M. P. M. and Barclay, L. W. (1991): Radio Wave Propagation, Peter Peregrinus Ltd, London, United Kingdom, pp. 23-60.

Kolawole, L. B. (1980): Climatological Variations of Surface Radio Refractivity in Nigeria. Bull. *Nig. Inst. Phys*., Vol.4, pp. 97-117

Lane, J. A. and Bean, B. R. (1963): A radio meteorological study, Part I: Existing Radio meteorological parameters; Part II: An analysis of V.H.F. field strength variations and refractive index profiles; Part III: A new turbulence parameter. *J. Res. Natl. Bur. Std*., D67, pp.589-604.

Morris, S. and William, O. (1973): Essentials of Communication Electronics, McGraw-Hill, pp. 2-4.

Owolabi, I. E. and Williams, V. A. (1970): Surface Radio Refractivity Patterns in Nigeria and in the Southern Cameroons. *J. West African. Science Association* 15, No.1, pp.3-17.

Oyedum, O. D. and Gambo, G. K. (1994): Surface Radio Refractivity in Northern Nigeria. *Nig. J. Phys*, Vol.6, pp. 36-41.

Oyedum, O. D. (2009): Seasonal Variation of Radio Field Strength and Radio Horizon in Nigeria. *Nigerian Journal of Pure and Applied Physics*, Vol. 5, pp. 97.

Oyedum, O. D., Igwe, K. C., Eichie, J. O. and Moses, A. S. (2009): Preliminary Results of Surface Refractivity in Minna, Niger State, Nigeria. Proc. of Annual Conference of Nigerian Union of Radio Science pp. 19-24.

Smith, E. K. and Weintraub, S. (1953): The Constants in the Equation for Atmospheric Refractive Index at Radio Frequencies. Proc. Inst. Radio Eng., 41, pp.1035-1037.

Valtr, P. and Pechac, P. (2005): Novel Method of Vertical Refractivity Profile Estimation Using Angle of Arrival Spectra, XXVIIIth General Assembly of international Union of Radio Science, New Delhi (India).